

ABSTRACT

This report details the zero speed seakeeping investigation of the new Roll-On/Roll-Off Discharge Facility (RRDF 2000) aft of the CAPE H and CAPE D Sealift ships. The sea conditions used were high sea states 2, 3, and 4 with wave headings every 15 degrees around the compass. The responses of concern are the body six-degree of freedom motions, ramp accelerations, and ramp twist.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

There is a continuing need to perform cargo loading and off loading at sea in support of amphibious operations. A Roll-On/Roll-Off Discharge Facility (RRDF) is located aft of a Roll-On-Roll-Off cargo ship. The ship's ramp extends to the RRDF. Vehicles and trailers are then "rolled" off the cargo ship onto the RRDF and from there to smaller, faster transport to shore.

To support that effort it is important to know the motions of the cargo ships, the RRDF, and cargo as it is being moved. This study is in a similar vein to the TAKR-RRDF model test and theoretical predictions made in 1997¹. This theoretical study uses the new RRDF 2000 and the CAPE D (Domingo) and CAPE H (Henry) Sealift ships. The two body (CAPE D/H and RRDF) configurations are evaluated in operational sea states at heading from 0-360 degrees. The six degree of freedom motions are: surge, sway, heave, roll, pitch, and yaw. The most important ramp responses are ramp endpoint and midpoint accelerations and ramp twist. The investigation only considered zero speed and both long and short crested waves conditions.

WAMIT DETAILS

The study used Wave Analysis MIT (WAMIT) to generate the zero speed motion transfer functions for each body. WAMIT is a three dimensional radiation-diffraction panel program for zero speed wave-body interaction. Each of the bodies is represented by a surface comprised of flat panels. Generally, the more panels, the more accurate the solution.

This study used 30 wave frequencies (ω) from 0.3 to 2.5 rad/sec or 20.9 to 2.5 seconds. The frequencies used were: 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1., 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, and 2.5 rad/sec. These frequencies cover the range of sea spectra energy.

¹ Applebee, T., D. Hayden, R. Bishop, T. Smith, "T-AKR 296/RRDF Ramp Model Test," CRDKNSWC-HD-1421-05 (Mar 1997).

Wave headings relative to bodies were every 15 degrees from 0-360 degrees, i.e., both port and starboard headings. WAMIT uses the definition where 0 degrees is following seas; 90 degrees is starboard beam waves (waves traveling in +y direction); 180 degrees is head seas; and 270 degrees is port beam waves (waves traveling in -y direction). Stated in another way, the heading angle is the angle between the direction of wave propagation and the positive X axis. Long crested seas are an extreme case; whereas short crested seas are more realistic.

Acceleration is $-\omega^2$ times the displacement. Ramp midpoint accelerations are the complex average of the ramp endpoint accelerations. Ramp twist is the complex difference of the roll motion for each body. The response values presented in this report are root mean square (RMS). To get significant single amplitude values multiply by 2. To get an “8 hour maximum²” amplitude multiply by 4.

COORDINATE SYSTEM

WAMIT uses a right handed coordinate system with z positive upwards. The response is calculated about the coordinate system origin, not necessarily the center of gravity. Furthermore, the free surface is always taken to be $Z = 0$. The difference between the origin and the center of gravity is accounted for with off diagonal terms in the mass matrix. The lack of symmetry in the RRDF results in off diagonal inertia terms irrespective of coordinate system.

The local coordinate system of each body has the origin at the longitudinal and transverse centers of buoyancy (LCB and TCB) at the waterline. The LCB and TCB locations are coincident with the LCG and TCG locations for a freely floating body.

The global coordinate system origin is located at the ship local coordinate system origin. The ship is always taken to be body 1 in the two body system.

RELATIVE LOCATION

From the PowerPoint presentation, the ramp touches down on the 1x4 rectangle. The actual touch down point is taken to be 15 ft (4.57m) from the front of the RRDF longitudinally and centered on the 1x4 rectangle transversely. Relative to the RRDF center of buoyancy, this point is 89.5 ft (27.3m) forward and 9.6 ft (2.9m) to port.

Based on drawing for the CAPE H ramp, the ramp foot was taken to be 11% of the overall length. The drawings provided were not dimensioned. The foot was not less than 10 ft (3.05 m).

The ramps were designated stern quartering for the CAPE D and CAPE H. No information was provided as to the ramp slew angle. The RRDF was positioned directly astern the ships, with the ship centerline aligned between modules 13-14-15-38 and 16-17-18-39, see Figure 1. Thus, the RRDF center of buoyancy is offset transversely by 9.6 ft (2.9m) to starboard. Due to the relatively large distance between the ship and RRDF, the sheltering effect is minimal and the astern position is representative.

² Eight hours assumes approximately 3000 encounters of 9.7 sec waves. Shorter period waves will take less time for 3000 encounters.

SEA CONDITIONS

The sea conditions chosen by the sponsor were a high sea state 2, 3, and 4, significant wave heights of 3 ft (0.9m), 5 ft (1.5m), and 8 ft (2.4 m), respectively. The spectral definition used was a Pierson-Moskowitz with these significant wave heights. These spectra are equivalent to Bretschneider spectra with modal periods of 4.78, 6.17, 7.81 seconds for sea states 2, 3, and 4. These wave heights and periods are similar to the NATO standard sea state definitions except for sea state 2 where the modal periods are 2 seconds apart, 4.78 versus 7.5 seconds.

Pierson-Moskowitz is a single parameter spectrum based on wind speed. Bretschneider is a two-parameter spectrum using significant wave height and modal period. However, Pierson-Moskowitz and Bretschneider sea spectra have the same equation, but use different constants. So with proper selection of parameters, the spectra can be made identical.

The study used infinite water depth as a general case. Shallow water effects in water depths greater than 150 ft (45.7 m) are minor for the modal periods of these sea states.

CAPE D

The CAPE D WAMIT hull description was generated from offset points read from a body plan drawing and entered into MULTISURF. MULTISURF is a surfacing program that allows easy changes in draft and trim and outputs WAMIT compatible geometry definition files (GDF). The hull is described with 2,832 panels. Results were checked for convergence and irregular frequencies.

The loading conditions were provided by the sponsor. The loading condition chosen was full draft.

Table 1. CAPE D (Domingo) principal dimensions.

Length ft (m)	634.00	(193.24)
Beam ft (m)	97.00	(29.57)
Draft ft (m)	32.40	(9.88)
Displacement lton (tonne)	36,122	(36,712)
GM ft (m)	4.29	(1.31)
Kxx ft (m)	36.37	(11.10)
Kyy ft (m)	158.48	(48.31)
Kzz ft (m)	158.48	(48.31)

The aft ramp point is 301.5 ft (91.9 m) aft, on centerline, and 11.4 ft (3.5 m) up from the WAMIT origin, i.e., the center of buoyancy at the waterline. The vertical location was determined from the provided drawings.

CAPE H

The CAPE H hull description was generated from a Standard Ship Motion Program input file. This study did not use the existing WAMIT discretization with 478 panels. This analysis used a 1,586 panel representation. Results were checked for convergence and irregular frequencies, by comparing the results with a 6,344 panel representation. Results were identical except at the longest two periods for sway, roll, and yaw.

The loading condition uses was the full load departure displacement used in the MOB analysis.

Table 2. CAPE H Principal dimensions.

Length ft (m)	689.00	(210.00)
Beam ft (m)	105.83	(32.26)
Draft ft (m)	28.12	(8.57)
Displacement lton (tonne)	37,793	(38,400)
GM ft (m)	5.86	(1.79)
Kxx ft (m)	42.33	(12.9)
Kyy ft (m)	172.25	(52.5)
Kzz ft (m)	172.25	(52.5)

The aft ramp point is 329.24 ft (100.4 m) aft, on centerline, and 11.4 ft (3.5 m) up from the WAMIT origin, i.e., the center of buoyancy at the waterline. The vertical location was determined from the provided drawings.

RRDF

The RRDF is made of 34 flat end modules, 6 male ramp modules, and 128 male-to-male connectors. The overall shape can be viewed as three rectangles –1x4, 3x10, and 3x2 modules, connected together. Figure 1 shows the basic shape of the RRDF. The light gray numbers (13, 16, 19, 22, 25, 28) are the male ramp modules.

1	2	3	7	8	9	
4	5	6	10	11	12	37
			13	14	15	38
			16	17	18	39
			19	20	21	40
			22	23	24	
			25	26	27	
			28	29	30	
			31	32	33	
			34	35	36	

Figure 1. RRDF with numbered modules.

The length overall is 266 ft (81.1m); the widest beam is 80 ft (24.4m). The overall RRDF and piece dimensions and weights are in Table, 3.

Table 3. RRDF overall and piece dimensions and weights.

	Length ft (m)	Width ft (m)	Depth ft (m)	Displace. lt (mt)
RRDF	266.00 (81.1)	80.00 (24.4)	2.32 (0.71)	811.8 (825.2)
Flat End	38.00 (11.58)	8.04 (2.45)	7.87 (2.40)	17.2 (17.5)
Ramp Male	38.00 (11.58)	8.04 (2.45)	7.87 (2.40)	10.7 (10.9)
Male – Male Connector	1.25 (0.38)	1.25 (0.38)	7.87 (2.40)	1.5 (1.5)

All the pieces are assumed rigidly connected together. Because the modules do not have the same displacement, they will float at different drafts individually. This causes heel and trim for the total unit due to a difference in location of the centers of gravity and buoyancy. See Table 4 for locations.

The heel and trim are 0.024 deg and 0.159 deg, respectively. The difference in draft due to heel is negligible. The difference in draft for trim is 0.74 ft (0.22m) between the bow and stern. A separate study showed very little difference between drafts of, 1.82 ft (0.55m) and 2.31ft (0.71m) for all motions except yaw. As a result, little difference is expected between the even keel and trimmed RRDF. Thus, the RRDF was paneled as floating on even keel using 1015 panels. The mass matrix reflects the mix of different units.

Table 4. RRDF center of gravity and buoyancy locations from bow, port edge, and baseline.

	X ft (m)	Y ft (m)	Z ft (m)
CG	100.42 (30.61)	33.71 (10.27)	3.94 (1.20)
CB	104.50 (31.85)	33.61 (10.24)	1.16 (0.35)

The ramp touch down point is 89.5 ft (27.3 m) forward, 9.6 ft (2.9 m) port, and 5.57 ft (1.7 m) up from the WAMIT origin, i.e., center of buoyancy at waterline.

RESULTS

The irregular seas results were calculated using WAMIRGW which uses the WAMIT regular wave transfer functions and input sea state parameters. The values presented are root mean square (RMS). Multiply these values by two to get single significant amplitude values; by four for significant double amplitude (height) values.

Generally, the ships had very little response and acted as stationary bodies. The CAPE D and CAPE H had essentially the same motions and had symmetric response port and starboard. The larger ramp accelerations on the ship end were due to the stern location and height above the waterline.

The RRDF did move. Its responses were roughly independent of ship, because the ships are very similar. The RRDF motions had little affect on the ship response as evidenced by the symmetric ship response. The ships did provide significant sheltering at headings ± 30 degrees from head seas in long crested seas. The sheltering effect is much

less in short crested seas, though due to spreading even beam headings have some sheltering. Long crested RRDF heave, behind the CAPE H, in sea state 3 head seas decreased from 0.371 ft (0.11m) to 0.198 ft (0.06m). The same conditions in short crested seas saw a decrease from 0.446 ft (0.14m) to 0.41 ft (0.13m). The RRDF response was asymmetric port-starboard due to the asymmetric geometry, rather than sheltering.

The long crested results have higher peaks and lower valleys when plotted by heading than the short crested results. The short crested results smooth out the smaller heading variation shown on the long crested results. This report cites the largest long crested results, regardless of heading. The largest short crested values are generally on the order of 60% the largest long crested.

CAPE D

The six degree of freedom motions for sea states 2, 3, 4 were very small. Also the response is very nearly symmetric about head/following seas as expected. Sea states 2 and 3 have less than a half foot (0.15m) of translation and less than 0.1 degrees of rotation at all headings, with one exception. The exception being sea state 3 beam seas in heave, 0.594 ft (0.18m).

In sea state 4, the response is still small. The largest translations are sway and heave, 0.88 ft (0.27 m) and 1.68 ft (0.51 m) respectively in beam seas. Maximum roll and pitch occur in quartering seas and are 0.15 and 0.28 degrees, respectively.

Longitudinal acceleration at the ramp top is less than 0.003 g's for sea states 2, 3, and 4 at all the headings examined. Lateral acceleration is on the order of half the vertical acceleration. The largest lateral acceleration calculated was 0.0189 g's in sea state 4 beam seas. The largest vertical acceleration calculated was 0.0378 g's in sea state 4 beam seas.

CAPE H

The six degree of freedom motions for sea states 2, 3, 4 were very small. Also the response is fairly symmetric about head/following seas as expected. Sea states 2 and 3 have less than a half foot (0.15m) of translation and less than 0.1 degrees of rotation at all headings, with one exception. The exception being sea state 3 beam seas in heave, 0.563 ft (0.17m).

In sea state 4, the response is still small. The largest translations are sway and heave, 0.87 ft (0.27 m) and 1.56 ft (0.48 m) respectively in beam seas. Maximum roll and pitch occur in quartering seas and are 0.19 and 0.29 degrees, respectively.

Longitudinal acceleration at the ramp top is less than 0.003 g's for sea states 2, 3, and 4 at all the headings examined. Lateral acceleration is on the order of two-thirds the vertical acceleration. The largest lateral acceleration calculated was 0.0198 g's in sea state 4 beam seas. The largest vertical acceleration calculated was 0.0312 g's in sea state 4 starboard bow quartering (315 degrees).

RRDF

The response of the RRDF was nearly independent of the ship. As expected, the response is not symmetric about head/following seas given the asymmetric shape of the RRDF. The most obviously large response is roll, which is 1.2, 2.1, and 2.9 degrees in port beam seas for sea states 2, 3, and 4, respectively. Pitch is also large, ranging from 0.23 to 1.22 degrees for sea states 2 and 4, respectively. RRDF heave and sway are the same order of magnitude as the CAPE's heave and sway.

Longitudinal acceleration at the ramp bottom is less than 0.017 g's RMS for sea states 2, 3, and 4 at all the headings examined. The largest lateral acceleration is 0.017, 0.026, and 0.038 g's RMS for sea states 2, 3, and 4, respectively. The worst heading for lateral acceleration was 90 degrees, starboard beam seas. The largest vertical acceleration calculated was 0.074 g's in sea state 4 beam seas. The largest vertical accelerations in sea states 2 and 3 were 0.041 and 0.060 g's RMS.

The accelerations at the ramp midpoint are on the order of the average of the ramp end accelerations. The largest longitudinal acceleration is less than 0.01 g's rms in sea state 4. The largest lateral accelerations occur in starboard beam seas and are less than 0.0275 g's RMS in sea state 4. The largest vertical accelerations range from 0.021, 0.033, and 0.046 g's RMS in sea states 2, 3, and 4. The worst heading for vertical acceleration is 270 degrees, port beam seas.

The RRDF roll motion dominates the ramp twist because the CAPE's roll is small in comparison. Using RRDF roll motion as the ramp twist is slightly conservative and poses no serious loss of accuracy. For instance in sea state 4, the largest RRDF roll is 2.95 degrees and the ramp twist 2.88 degrees. Furthermore, they both have the same trends with respect to heading.

PLOTS

The last pages of this report are plots of the described response with respect to heading for all three sea states. Each of the plots is labeled with descriptive titles and units. The first six plots are heave, roll, and pitch for the CAPE D and CAPE H in long crested seas. CAPE H being on the left and CAPE D on the right of the page. The responses of one ship is similar to the other in terms of general trends and magnitude.

The next six plots are heave, roll, and pitch for the RRDF, located behind the CAPE D and CAPE H in long crested seas. They show the RRDF motions being very similar to one another. The CAPE H – RRDF results on the left of the page. The CAPE D – RRDF results are on the right of the page.

The next six plots are ramp accelerations, top, bottom, and middle, for CAPED-RRDF and CAPEH-RRDF conditions. The next two plots are ramp twist for CAPED-RRDF and CAPEH-RRDF conditions. These plots show that the CAPED-RRDF and CAPEH-RRDF configurations have similar motions, and they are not symmetrical port and starboard. The CAPE H results are on the left; CAPE D results on the right of the page.

The next eight plots show the response for the RRDF alone in long and short crested seas. Long crested results are on the left and short crested on the right. The

responses plotted are ramp bottom vertical acceleration, heave, roll, and pitch. They show the natural asymmetry of the response without sheltering effects.

The last eight plots show the response of the RRDF with and without the CAPE's. The results plotted are for sea state 3 and are representative. They show small differences between the CAPE D and CAPE H results and significant sheltering ± 30 degrees from head seas (180 degrees) in long crested seas. The sheltering is seen by the RRDF alone responses being larger than when behind the CAPE's. Long crested results are on the top of the page; short crested on the bottom. The responses plotted are heave, roll, pitch, and ramp bottom vertical acceleration.

















